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(54) SUPERCONDUCTOR CABLES

(71) We, SIEMENS AKTIENGESELLSCHAFT, a German Company, of Berlin and Munich, Germany, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement: —

The invention relates to superconductor cables.

In a superconductor cable for alternating-current, there may be at least one pair of coaxial conductors disposed in a coolant tube and preferably assembled from prefabricated sections, of which a tubular inner conductor is separated from a tubular outer conductor by a plastics insulation. For example, in the case of three-phase current cables, three such coaxial conductor pairs may be provided. The inner conductor of each conductor pair may serve as the outgoing conductor and the outer conductor as the return conductor, which is generally at earth potential. Interlinking of the phases is generally effected outside the actual cable. An electro-magnetic field in such coaxial conductor pairs is formed in the space between the inner conductor and the outer conductor, while regions outside this space are substantially free from field. For insulation of the inner conductor from the outer conductor, the space between the two conductors may be exhausted of gas or filled with liquid helium, which then serves as an insulating medium. A proposal for a plastics insulation consisting of thin foils of stabilised polyethylene, by which the inner conductor is covered, is made in Elektrotechnische Zeitschrift, Edition B, Vol. 20 (1968), pages 273 to 277, more particularly page 275.

The inner conductor and the outer conductor of a coaxial conductor pair in such cables may consist of rigid tubes, preferably made of a metal having high electrical conductivity, such as high-purity copper or aluminium, to which superconductor material is applied in the form of a layer, the metal being electrically normally conductive at a temperature at which the superconductor material can conduct electricity superconductively. As superconductor materials for alternating current of 50c/s, pure niobium and lead have proved particularly suitable. Each of these superconductor materials has very low hysteresis losses if, during the operation of the cable, a corresponding lower critical magnetic field H_{c1} is not exceeded. In order that substantially no eddy current losses occur in the normally conducting tubes bearing the superconducting layer, the latter is situated on the outside surface of the inner conducting tube and on the inside surface of the outer conducting tube of the coaxial conductor pairs. During operation of the superconducting cable, and more particularly when the conductor pairs are insulated by a vacuum or by plastics, coolant (for example liquid helium) flows within the tubular inner conductor and on the outside surface of the tubular outer conductor in the coolant tube. The inner and outer conductors are then in direct contact with the coolant and are excellently cooled. The coolant tube itself is generally surrounded by a, for example, nitrogen-cooled tubular radiation shield, which in turn is surrounded by an outer protective tube. The space between the coolant tube and the outer protective tube is exhausted during the operation of the cable for the purpose of thermal insulation of the coolant tube. For further thermal insulation thin plastics foils may be provided within the exhausted space which foils may be coated, for example, with a reflecting metal layer. In

order to effect good thermal insulation of the coolant tube from the atmosphere surrounding the cable, the coolant tube, the radiation shield and the outer protective tube may be constructed as rigid tubes. Such rigid tubes may be satisfactorily held in their relative positions by a relatively small number of spacer members comprising material having good thermal insulation. In the laying of the superconducting cable, these rigid tubes are assembled from individual sections in situ and thermal-elongation-compensating members, particularly corrugated tube sections, may be provided in the coolant tube and in the radiation shield to balance out the differences in the contractions of the respective materials on cooling.

The inner and outer conductors, consisting of rigid tubes, of the individual coaxial conductor pairs must also be assembled from sections in situ. The length of these sections can scarcely exceed 50 m for reasons for transport. This results in the necessity of a large number of coupling points at which the superconducting layers of the sections must be connected together, for example by welding. Apart from the high expenditure thus involved, the probability of defective welds, and hence the probability of impairment of the current-carrying capacity of the superconductors, naturally increases with an increasing number of welds. In addition, different coefficients of expansion of the materials of such tubes having coatings of superconductor material presents considerable difficulties.

According to the present invention there is provided an electrical conductor comprising a strip of superconductor material formed as a helix extending coaxially along a tubular support structure, against the inside surface thereof, and a further strip of superconductor material formed as a helix extending coaxially along the tubular support structure, against the outside surface thereof, the arrangement being such that the two strips form together a coaxial conductor pair which is flexible together with the tubular support structure at room temperatures.

In one embodiment of such an electrical conductor, a tubular support which is flexible at room temperature forms a plastics insulation between inner and outer conductors each comprising a strip assembled from superconducting and electrically normally conducting metals and wound to form a single-layer helix, the helix which forms the inner conductor bearing against the inside surface of the tubular support, and the helix which forms the outer conductor being wound on to the outside surface of the tubular support, the inner helix being coaxial with the outer helix. A conductor pair thus constructed may be made in large lengths of, for example, several hundred metres and transported to the laying site on drums around which it is wound and there pulled into a coolant tube of a cable. If the cable is of such a length that the conductor pairs must be assembled from prefabricated sections, which will generally be the case, the number of coupling points along the cable, at which the superconductor conductors must be connected together in the layer, can be greatly reduced, relative to the number of coupling points that would be needed if rigid tubular conductors were used, owing to the large length of the sections. Since the plastics insulation is constructed as a support tube, a simple mechanical construction is obtained and at the same time there is adequate mechanical stability of the conductor pair. The inner and outer conductors each consisting of a single-layer helix are sufficiently flexible and are mechanically retained by the support tube. Coolant, which flows through the interior of the tubular support and along its outside surface during the operation of the cable, directly washes the conductor helices and thus excellently cools them, and thus the advantages of direct cooling obtained with rigid tubular conductors is retained. There may be employed as the superconductor material for alternating-current cables niobium, and in some cases lead. As electrically normally conducting metals serving for the electrical stabilisation of the superconductors, copper and aluminium are particularly suitable. By "electrically normally conducting metals" are meant in this context metals which are electrically normally conducting at the operating temperature necessary for bringing about the superconducting state, for example at about 4 to 5 K, in the superconductor material.

In the selection of the plastics for the insulating support tube of such conductor pairs, a number of viewpoints must be considered. In the first place, the plastics must have the highest possible dielectric strength in order that the wall thickness of the support tube, and hence the diameter of the external conductor, may be kept as small as possible. While the diameter of the inner conductor must be such that the maximum permissible magnetic field is not exceeded on the surface of the inner conductor, permissible diameters of the outer conductor depend substantially upon the dielectric strength of the insulating support tube. A small external conductor diameter facilitates the winding of the conductor pairs on to drums and furthermore makes it possible to keep small the diameter, and hence the surface, of the coolant tube and of the further tubes of the cable, which in turns results in a reduction of thermal losses, which are proportional to the cable surface.

Since the dielectric losses occuring in the insulating support tube must be dissipated by the liquid coolant, these losses should also be

minimised. The tan δ of the loss angle of the plastics employed for the support tube should therefore be of the order of magnitude of about 10^{-5} or lower at a temperature of about 4 to 5 K. In addition, the plastics should have a low dielectric constant. Moreover, it is advantageous for the elastic limit of the insulating support tube to be higher than the tensile stress set up in the support tube during the cooling to the operating temperature, which stress is equal to the product of the modulus of elasticity and the contraction. Since the support tube is only elastically deformed in the cooling if this condition is satisfied, a firm gripping of the conductor pairs at the cable ends or at the ends of the conductor pair sections is rendered possible, so that no additional features are required for balancing out thermal contractions or expansions. The tubular support of a conductor pair section may with advantage consist of a single continuous section. Suitable plastics are, for example, polyethylene, polytetrafluoroethylene and polyamides, such as nylon.

In addition, there must not occur in the insulating support tube, on cooling to the operating temperature of the cable, any cracks which might result in a reduction of the dielectric strength. Although the plastics already mentioned do not in themselves tend to crack under normal conditions, it is nevertheless advantageous for reasons of safety to build up the tubular support from two coaxial plastics tubes which are flexible at room temperature, and a multi-layer winding consisting of plastics foils, which is disposed between these tubes. The two coaxial plastics tubes, which may be made relatively thin, then ensure more particularly the mechanical stability, while the multi-layer winding consisting of plastics foils ensures high dielectric strength. It is particularly advantageous for the two plastics tubes to be impermeable to coolant, because no coolant can then penetrate into the insulation, and the formation of coolant vapour bubbles within the insulation is avoided. Preferably, there are employed for this purpose plastics tubes consisting of a nylon mesh rendered impermeable by heat treatment, while the plastics foils coiled between the plastics tubes advantageously consist of polyethylene fibre or polytetrafluoroethylene fibre paper.

If no importance is attached to the tubular support being impermeable to coolant, the tubular support of a conductor pair section may alternatively consist of a number of tubes which are aligned with one another and which mechanically interengage. By means of such a construction, the tubular support may be relieved of tensile stresses in the cooling.

For a better understanding of the invention, and to show how the same may be carried into effect, reference will now be made, by way of example, to the accompanying drawings, in which:—

Figure 1 shows a view of a section through a superconductor cable, perpendicular to the axis of the superconductor cable, embodying the invention,

Figure 2 shows a perspective view of a part of a coaxial conductor pair embodying the present invention,

Figures 3 and 4 show diagrammatically axial sectional views of respective parts of two coaxial conductor pairs embodying the present invention,

Figure 5 illustrates an axial sectional view of a connection between two coaxial conductor pairs embodying the present invention,

Figure 6 shows a cross-sectional view corresponding the line A—B of Figure 5,

Figure 7 shows a longitudinal sectional view of a connection between two conductors strips, and

Figure 8 diagrammatically illustrates a longitudinal sectional view of part of an electrical conductor embodying the present invention.

The principle of the construction of a super-conducting cable having a number of coaxial conductor pairs is illustrated by way of an example in the case of a three-phase current cable in Figure 1. Situated in a coolant tube 1 comprising high-grade steel are three coaxial conductor pairs 2 to 4. Each coaxial conductor pair comprises a tubular plastics support 5, against the inside surface of which there lies an inner conductor 6 coiled to form a helix, while there is helically wound on to its outside surface an outer conductor 7. During the operation of the cable, coolant 8, more especially liquid helium, flows through the free interior of each coaxial conductor pair and around the outside of the coaxial conductor pairs. The coolant tube 1 is surrounded by a radiation shield 9, comprising copper, which is cooled by liquid nitrogen flowing through the tubes 10. The radiation shield 9 is in turn enclosed in a protective tube 11, comprising high-grade steel. The space between the coolant tube 1 and the protective tube 11 is evacuated in the operation of the cable.

Part of an electrical conductor, in this case a coaxial conductor pair, for a cable according to Figure 1 is diagrammatically illustrated in Figure 2, in which the inner conductor 6 and the outer conductor 7 each consist of a strip coiled to form a single-layer helix. The inner conductor 6 lies in contact with the inside surface of the tubular support 5, while the outer conductor 7 is wound on to the outside surface of the tubular support 5. In the manufacture of the coaxial conductor pair the tubular plastics support 5, for example of polyethylene, may first be

made, whereafter the inner conductor 6 coiled in the form of a helix may be pulled into the tubular support, and the outer conductor 7 coiled around the tubular support 5. Alternatively, the inner conductor 6 may first be coiled to form a helix and then enclosed in the tubular support 5 by extrusion. The helical inner conductor 6 may in this case be supported by a winding core or mandrel until the tubular support 5 takes over the supporting function. The helices of the inner and outer conductors are advantageously wound with such an overlap in the manufacture that even after cooling to the operating temperature of the cable the strip edges of juxtaposed turns of each helix lie in close juxtaposition to one another or somewhat overlap one another at their superconducting layers. The overlap of the strip edges which is necessary at room temperature can readily be determined from the contraction of the conductor material. For example, a strip-form conductor composed of a copper layer and a superconducting niobium layer shrinks by about 0.32% on cooling from room temperature to the temperature of the liquid helium.

A particularly advantageous form of construction of a coaxial conductor pair is shown in Figure 3. In this form of construction, the tubular plastics support comprises two coaxial plastics tubes 31 and 32 which are flexible at room temperature and between which there is coiled a multi-layer winding 33 consisting of plastics foils. A particularly suitable material for the plastics tubes 31 and 32 is nylon, which only shrinks by about 1% on cooling from room temperature to about 4.2 K. The inside tube 31 may advantageously be produced by covering an inner conductor 34 already wound into the form of a helix by a multi-layer mesh of nylon filaments. After the covering, the nylon mesh may be rendered impermeable to coolant which is to be used for cooling the conductor pair when in operation by briefly heating it on its surface to a temperature of about 150°C. For this purpose the inner conductor 34 covered by the nylon mesh may be pulled through a tubular furnace. Thereafter, a plurality of layers of plastics foils, more especially consisting of polyethylene fibre paper or polytetrafluoroethylene fibre paper, are wound around the tube 31. In this case, it is necessary to ensure, as indicated in Figure 3, that the points of abutment between the turns of one layer are covered by a turn of the next layer in order that no short paths free from plastics foils may remain between the tubes 31 and 32. For the production of plastics tube 32, the winding 33 is thereafter again covered by a multi-layer nylon mesh, which is also rendered impermeable on the surface by heat treatment. A helical outer conductor 35 is then wound around the tube 32. The inner conductor 34 and the outer conductor 35 each comprise a copper strip 36, 37, which is coated on one side by a niobium layer 38, 39. In both cases the superconducting layers 38 and 39 are on the side of copper strip which is closer to the tubular support. This arrangement has the advantage that the normally conducting layers lie outside the field-filled space between the superconductors, and hence alternating-current losses in the normally conducting metal are avoided. On cooling from room temperature to the temperature of the liquid helium, the polyethylene foils shrink by about 2.6% and the polytetrafluoroethylene foils by about 2.2%, i.e. somewhat more than the nylon tubes. If the tubes 31 and 32 and the foils 33 are connected together at the ends of the tubular support, for example by adhesive bonding or by a suitable heat treatment, differences in thermal contraction or expansion between the material of the tubes and that of the foils is allowed for by virtue of the fact that the individual turns of the foil winding 33 draw apart somewhat on cooling. The tubes 31 and 32 may be, for example, about 1 mm thick, while the foil winding 33 may have a total thickness of about 1 to 2 cm and may consist of a plurality of plastics foils, each for example of a thickness of about 100 μ. The external diameter of the inner conductor helix 34 may in this case be about 6 cm, the copper strips 36, 37 of the inner and outer conductors being about 2 mm thick and the niobium layers 38 and 39 being about 0.5 mm thick. In addition to their impermeability to coolant, the tubes 31 and 32 have the advantage that they protect the plastics winding 33 lying between them from atmospheric influences, especially from moisture, when the cable is stored for a relatively long time or when it is laid in the open air.

Figure 4 illustrates in longitudinal section another form of construction of a coaxial conductor pair, wherein the tubular support of a section of a conductor pair consists of a number of plastics tube sections 41 to 43 placed together and mechanically interengaging. By means of such a construction, the tubular plastics support is relieved of tensile stresses in the cooling. Provided at one end of each tube section is a ring-shaped protuberance 44 and at the other end a circular groove 45, the protuberance of one section fitting into the groove of the next section. The protuberance 44 should be as long as possible and the groove 45 as correspondingly deep as possible in order that the gap 46 (between a protuberance and the corresponding groove) free from insulating material between the inner conductor helix 47 and the outer conductor helix 48 may be as long as possible. By somewhat bevelling the walls of the groove 45, it is possible to increase the flexibility of the tubular sup-

port in a region in which material of neighbouring tube sections overlap.

An advantageous method of connecting together two conductor pairs is illustrated in Figures 5 to 7. The external diameter of tubular supports 51 and 52 of the two conductor pair sections is reduced at their ends 53 and 54. For the connection of the two ends, a tube section 55 is first so pushed into them that it lies with its two ends respectively inside inner conductor helices 56 and 57. The tube section 55 is built up of two concentric layers; the outer layer 58 consists of niobium, and the inner layer 59 consists of copper, which serves for the electrical stabilisation of the niobium. For the electrical connection of the inner conductors 56 and 57, stabilising copper 62 is first removed at ends 60 and 61 of the inner conductors, so that the conductor ends then only consist of niobium 63. Thereafter, the conductor ends 60 and 61 are disposed around the outside of the tube section 55 and connected, for example by welding, to the outside surface 58 of the said tube section, this surface also consisting of niobium. A plastics sleeve consisting of two half-tubes 64 and 65 is then laid around the point of connection. A second plastics sleeve consisting of two half-tubes 66 and 67 is then disposed around the said sleeve and the ends 53 and 54, of reduced external diameter, of the tubular supports 51 and 52. As is shown in Figure 6, the gaps between the two half-tubes of each sleeve are offset in relation to one another, so that paths along free gaps between the inner conductor and the outer conductor of the cable are as long as possible. Ends 68 and 69 of the helical outer conductors of the two conductor pair sections are then laid around the sleeve consisting of the half-tubes 66 and 67. One possible method of connecting the ends 68 and 69 is shown in Figure 7. The stabilising copper 70 is first removed at the ends, so that the superconducting niobium 71 is exposed. The niobium ends 71 of the two conductors are then welded together at 72. If the plastics material of the sleeve consisting of the half-tubes 66 and 67, about which the conductor ends 68 and 69 are laid in the welding, should not withstand the welding temperature, there may be provided in this sleeve inserts 73 and 74 in the form of half-tubes, which consist of heat-resistant material, for example ceramics or asbestos. Finally, for the connection of the stabilising copper 70, after the welding of the niobium ends 71, a copper strip 75 is laid on and welded to the stabilising copper 70 at 76 and 77. Another advantageous possible method of connecting the ends 68 and 69 of the outer conductors resides in providing, for example instead of the inserts 73 and 74 in the form of half-tubes consisting of heat-resistant material, a sleeve formed of two half-tubes consisting of superconductor material, in the present example niobium, and connecting the niobium ends 71 of the two outer conductors to the outside surface of the said sleeve, for example by welding. Thereafter, the two conductor ends of stabilising copper 70 are again connected together. The described connecting technique has the particular advantage that it can readily be carried out and that the direct cooling of the inner conductor and of the outer conductor by the coolant can occur at the particular critical points of connection.

Some important electrical and mechanical data of the plastics hereinbefore mentioned are given in the following Table.

	Polyethylene	Polytetra-fluoroethylene	Nylon
tan δ at 4.2 K	$1.5 \cdot 10^{-5}$	$1.2 \cdot 10^{-6}$	$2 \cdot 10^{-5}$
Dielectric constant ϵ at 4.2 K	2.25	2.1	2.4
Dielectric strength at 4.2 K	92 kV/mm	134 kV/mm	111 kV/mm
Contraction e	2.6%	2.2%	0.97%
Modulus of Elasticity E at 293 K	200—1400 N/mm^2	350 N/mm^2	1700 N/mm^2
Tensile stress e·E set up	5.2—36.4 N/mm^2	7.7 N/mm^2	16.5 N/mm^2
Tensile strength at 293 K	8—33 N/mm^2	20 N/mm^2	50—55 N/mm^2

With regard to the tabulated values, it is to be noted that the tensile strength is substantially higher at low temperature than at the temperature of 293 K for which the values are as indicted in the Table.

In Figure 8, there is shown part of a strip-form inner conductor helix which is in contact with the inside surface of a tubular plastics support 81 and in which successive turns overlap one another at their superconducting layers to such a degree that adjacent edges of the superconducting layers of successive turns maintain contact even after the conductor is cooled to a temperature at

which the superconductor conducts electricity superconductively. The superconducting layer 82 is offset in relation to the normally conducting layer 83 of the strip so that it projects beyond one strip edge and is set back in relation thereto at the other strip edge. Such a strip may be made, for example, by plating a copper strip 83 with a niobium strip 82. This overlapping method has the advantage that no additional losses occur in the copper at the edges of the strip due to magnetic field irregularities at the edge of strip 82. The helical construction of the conductor allows for different degrees of thermal expansion or contraction between the tubular plastics support and the conductor, since the helix can draw apart in the longitudinal direction.

The tube 55, of Figure 5, alternatively to the metal structure hereinbefore described may comprise plastics, in which case the corresponding ends of inner and outer conductors of the two conductor pairs that are being joined are connected directly to one another.

The flexible, coaxial conductor pairs which embody the invention may, of course, also be employed in cables in which the coolant tube, the radiation shield and the outer protective tube are made flexible, for example from corrugated tube. It is also possible in such cables to make use of advantageous properties of the conductor pairs, particularly their ready transportability. In order to obtain sufficient mechanical stability in such cables, however, there must be provided between the flexible outer tubes numerous distance pieces, which impair thermal insulation. Cables having a rigid coolant tube, a rigid radiation shield and a rigid protective tube are therefore preferred.

WHAT WE CLAIM IS:—

1. An electrical conductor comprising a strip of superconductor material formed as a helix extending coaxially along a tubular support structure, against the inside surface thereof, and a further strip of superconductor material formed as a helix extending coaxially along the tubular support structure, against the outside surface thereof, the arrangement being such that the two strips form together a coaxial conductor pair which is flexible together with the tubular support structure at room temperatures.

2. A conductor as claimed in claim 1, wherein the tubular support structure comprises electrically insulative plastics material.

3. A conductor as claimed in claim 1 or 2, wherein the tubular support structure consists of a single continuous piece of material.

4. A conductor as claimed in claim 1 or 2 wherein the tubular support structure comprises two coaxial plastics tubes with plastics foils formed as a multi-layer winding disposed between them.

5. A conductor as claimed in claim 4, wherein the two plastics tubes are impermeable to a coolant fluid used for cooling the conductor when the conductor is in use.

6. A conductor as claimed in claim 5, wherein each of the two plastics tubes comprises a nylon mesh rendered impermeable to the said coolant fluid by heat treatment and the said plastics foils comprise polyethylene fibre or polytetrafluoroethylene fibre paper.

7. A conductor as claimed in any one of claims 1, 2, 4, 5 and 6, wherein the tubular support structure comprises a series of separately made portions which are interengaged end to end.

8. A conductor as claimed in any preceding claim, wherein each strip of superconductor material forms a layer on and along one face of an associated metal strip which is electrically normally conductive at an operating temperature at which the superconductor material is in the superconductive state, the superconductor strip being between the associated metal strip and the said tubular support structure.

9. A conductor as claimed in claim 8, wherein the or each such metal strip is such that one of its edges projects laterally beyond the adjacent edge of the superconductor strip extending therealong, and the other of its edges is set back from the other edge of that superconductor strip.

10. A conductor as claimed in any preceding claim, wherein each helix is so formed that adjacent turns thereof are closely juxtaposed to one another, or overlap one another, at the strip edges when at a temperature at which the superconductor material is in the superconductive state.

11. An electrical current transmission line made up of first and second conductors, each being a conductor as claimed in claim 1, connected together with the aid of a tubular member having opposite ends inserted respectively into adjacent end portions of the first and second conductors, the respective tubular structures of the first and second conductors being of reduced external diameter at the said adjacent end portions, a connection between the respective inner superconductor strips of the first and second conductors being made on the outside surface of the said tubular member, which connection is surrounded by tubular insulating structures made up of axially extending portions of arcuate cross-section, and the respective further superconductor strips of the first and second conductors being led around the outermost surface of the tubular insulating structures to an electrical connection between those strips.

12. A transmission line as claimed in claim 11, wherein the said tubular member com-

prises an outside layer of superconductor material and an inside layer, in contact with the outside layer, of a material which is electrically normally conductive at a temperature at which the superconductor material is in the superconductive state, the respective inner superconductor strips of the first and second conductors being in electrical contact with the outside layer of the tubular member.

13. A transmission line as claimed in claim 11 or 12, wherein a tubular structure made up of axially extending superconductor portions of arcuate cross-section is disposed coaxially around the said outermost surface, and the respective further superconductor strips are connected electrically to the outer surface of this tubular structure.

14. An electrical conductor as claimed in claim 1, substantially as hereinbefore described with reference to Figure 2, Figures 2 and 3, Figures 2 and 4, or Figures 2 and 8 of the accompanying drawings.

15. An electrical current transmission line, substantially as hereinbefore described with reference to Figures 5, 6 and 7 of the accompanying drawings.

16. A superconductor cable, comprising a plurality of conductors, each being a conductor as claimed in any one of claims 1 to 10 and 14, or of transmission lines, each being a transmission line as claimed in any one of claims 11 to 13 and 15, extending alongside one another within a common coolant tube.

17. A superconductor cable substantially as hereinbefore described with reference to Figure 1 of the accompanying drawings.

HASELTINE, LAKE & CO.,
Chartered Patent Agents,
28 Southampton Buildings,
Chancery Lane,
London WC2.
Agents for the Applicants.

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1340983 COMPLETE SPECIFICATION

2 SHEETS This drawing is a reproduction of the Original on a reduced scale
Sheet 1

FIG. 1.

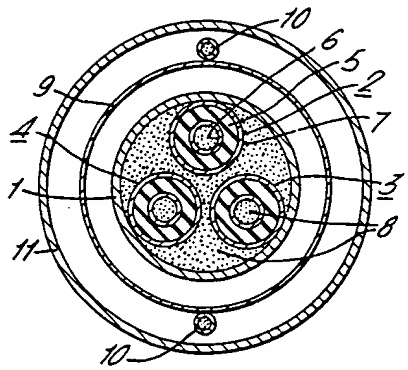

FIG. 2.

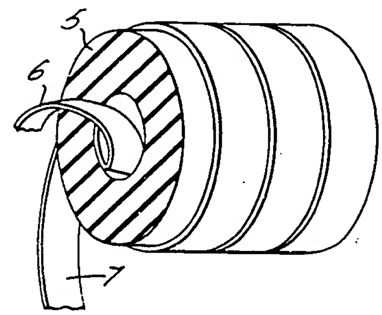

FIG. 3.

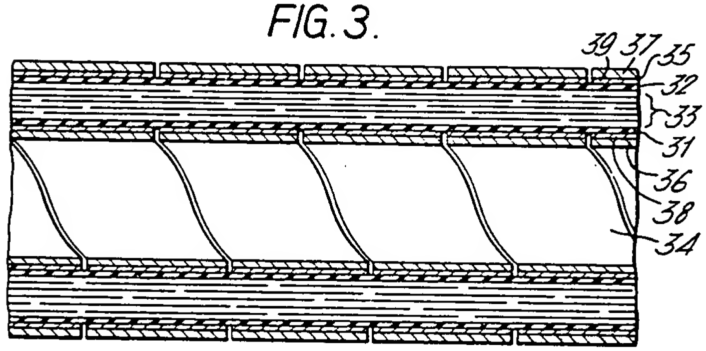

FIG. 4.

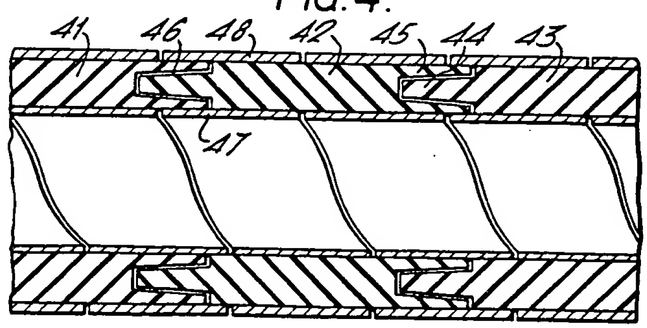

FIG. 5.

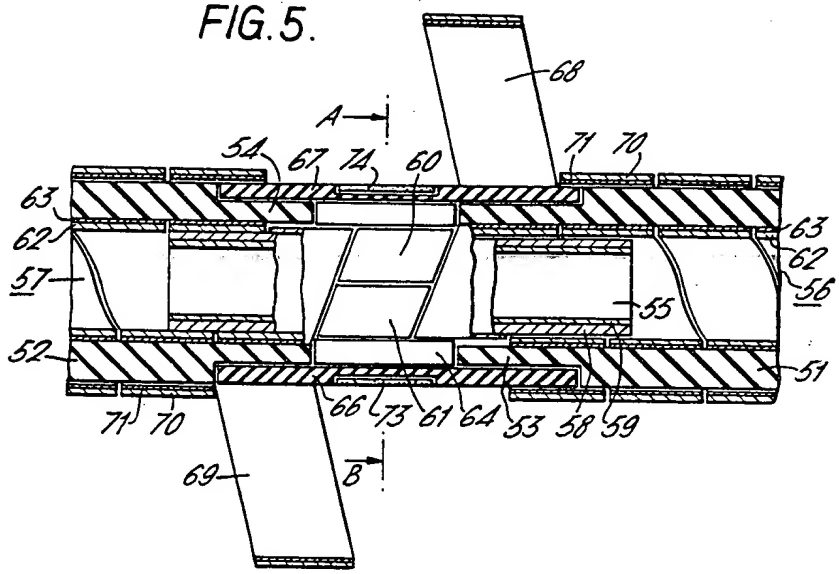

FIG. 6.

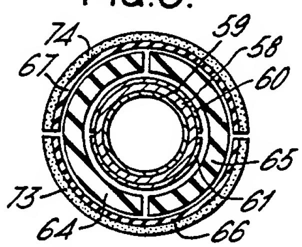

FIG. 7.

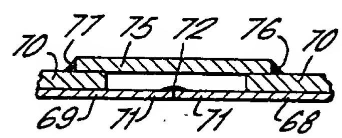

FIG. 8.